

HEDLP Opportunities for IFE

**Based Upon Discussions at the Inaugural IFE Science
and Technology Strategic Planning Workshop
San Ramon, California, April 24 - 27, 2007**



**Ed Synakowski
Fusion Energy Program Leader, LLNL**

May 23 - 24, 2007

Important developments make this an excellent time to assess the status of IFE and its science



- The stakes are now recognized as enormous. The climate change dialogue has shifted from “whether” and “what if” to “what now?”
- NIF ignition will fundamentally alter the scene and cast attention on fusion, IFE, and the science underpinning it like never before
- New experiments and computational capability are ushering in a new age of exploration of HEDLP system, and the science at the heart of HEDLP is rich
- The Office of Science and NNSA recognize the excitement and potential of HEDLP, the science of the fusing IFE target.

==> *The IFE community held a national workshop, April 24 - 27, near Livermore*

What happened at the workshop, and what the product will be ...



- About 115 registrants
- 3.5 days. Talks with lots of discussion time; breakout sessions. Mostly U.S., with strong talks from Japan and the U.K.
- 1 day specifically on HEDLP opportunities & issues, w/ breakouts. Other days also had some HEDLP-related talks and discussion
- Proceedings will be published in the Journal of Fusion Energy

Overarching conclusions:

The IFE community is eager to develop high rep-rated facilities to with the end goal an energy source that can make a difference to the world, and seeks programmatic support to pursue this.

Particular to this HEDLP workshop: *The attendees eagerly embrace the opportunity to advance IFE science through HEDLP research*

The scientific questions are compelling and the emergent opportunities with new tools are important in defining the IFE vision

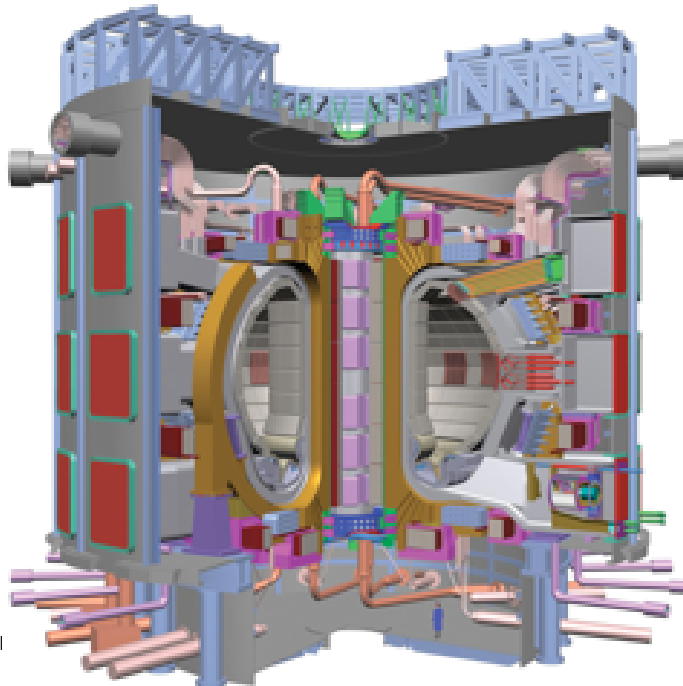
The potential impact is enormous

The meeting timing was driven by a sense of urgency: the age of burning plasmas is upon us, and we have an obligation in IFE to respond

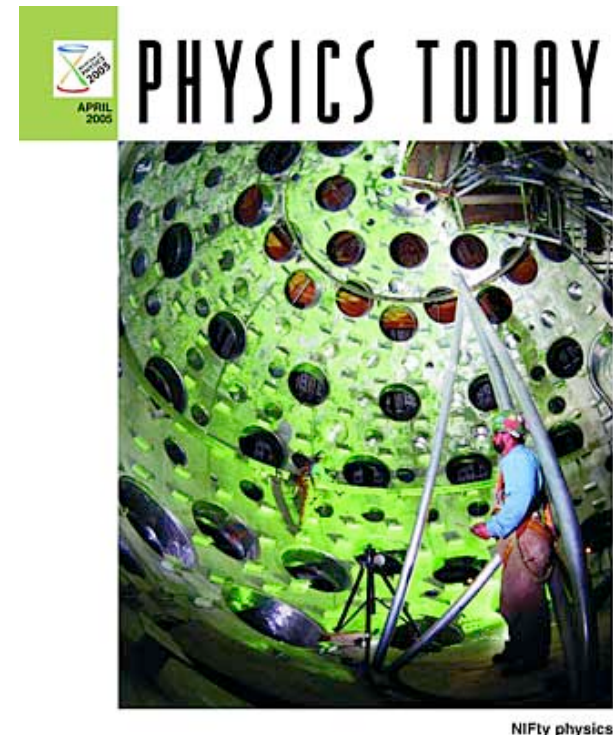


- Seven governments representing 1/2 of the world's population are partners in the ITER project
- NIF ignition will be the event - with HEDLP science at its core - to herald in this new age

The question from the world upon ignition will be:
“What is your energy strategy?”



Synakowski HI



All the program elements for an IFE R&D program were discussed. HEDLP will have a large impact on the optimal vision



The IFE R&D program rolls back from this

**World IFE Program
~2007-2020**

HEDLP

Target optimization
NIF, Omega, LMJ, Z...

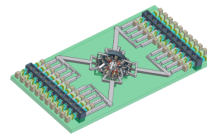
Rep-ratable drivers
("beamlets")

Chambers
(liquid,solid) and
nuclear technology

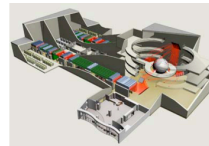
Support technology
(target fab, injection,
optics...)

Synakowski HEDLP Workshop May 23-24 '07

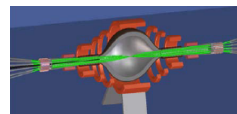
**High Average Fusion
Power Facility
~2015-2025**



NRL's FTF



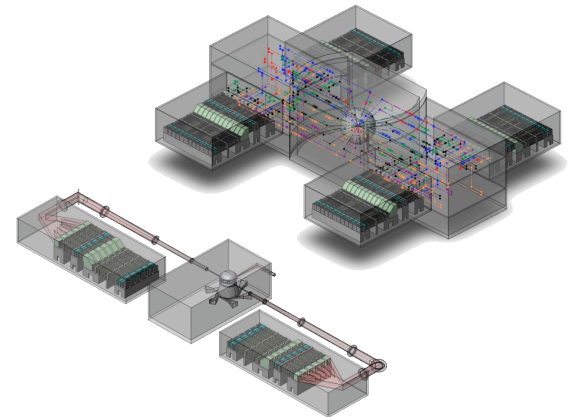
HiPER



HI-FTF, etc...

- High av. power 10's-100's MW
- Demonstrates sustainable fusion energy in steady-state
- Not req'd to demonstrate commercial viability

**Attractive Commercial
Plant Competitive with
Advanced (Breeder)
Fission**



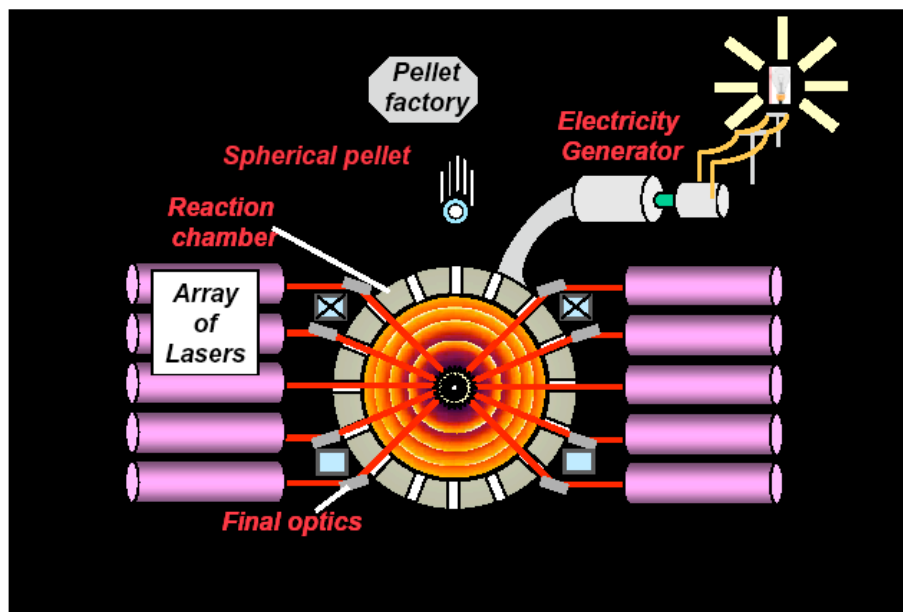
- Electricity (>1GWe)
- Hydrogen production
- Desalinated water
- Fission hybrid (breed/transmute)
- Etc,

Some background on long-range visions: (1)

We heard from the HAPL program, where much laser IFE research is performed



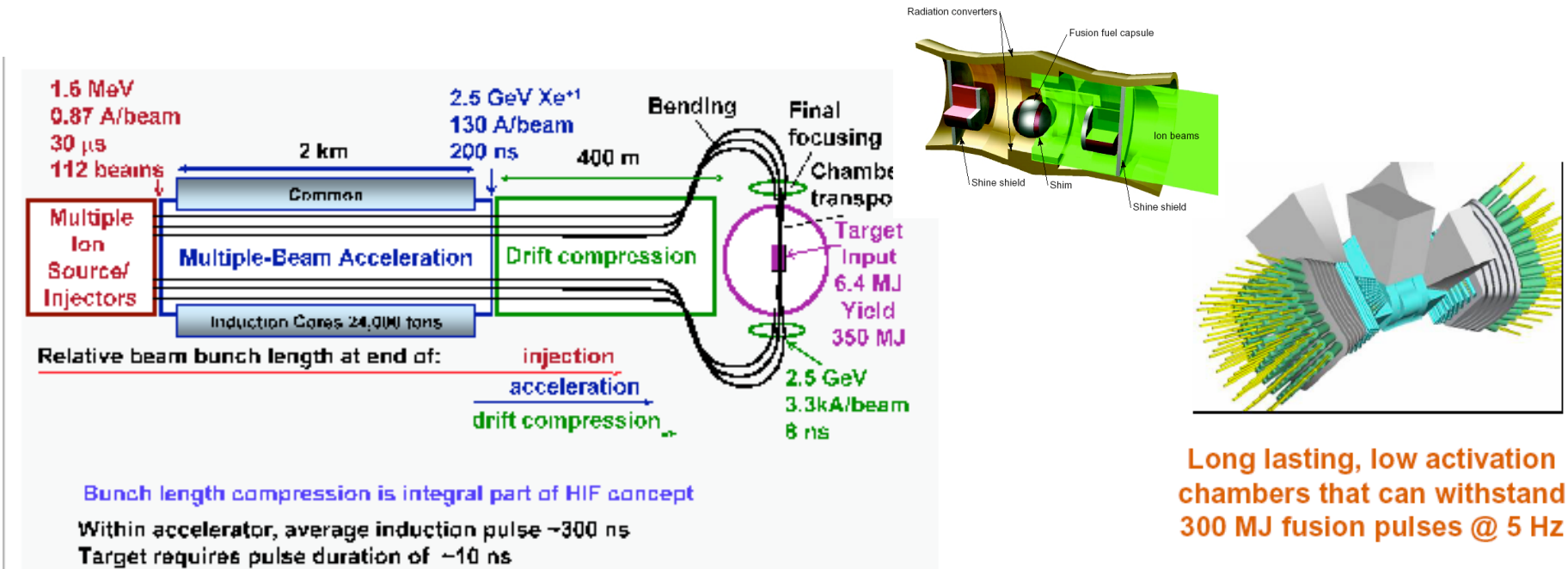
- HAPL: High Average Power Laser (HAPL) program. Laser-driven IFE R&D. Administered by NNSA.
- HAPL includes both **KrF & Diode Pumped Solid State Laser (DPSSL)** options
 - KrF progress was described
 - DPSSL prospects discussed - application of existing technologies; potential for “blue-sky” ideas
- HAPL focus: *the integrated problem*. Particular attention to a particular vision for an FTF (NRL (direct drive, dry wall, 5 Hz, ~ 150 MW, research tool)



(2) Another mainline approach discussed was heavy ion fusion



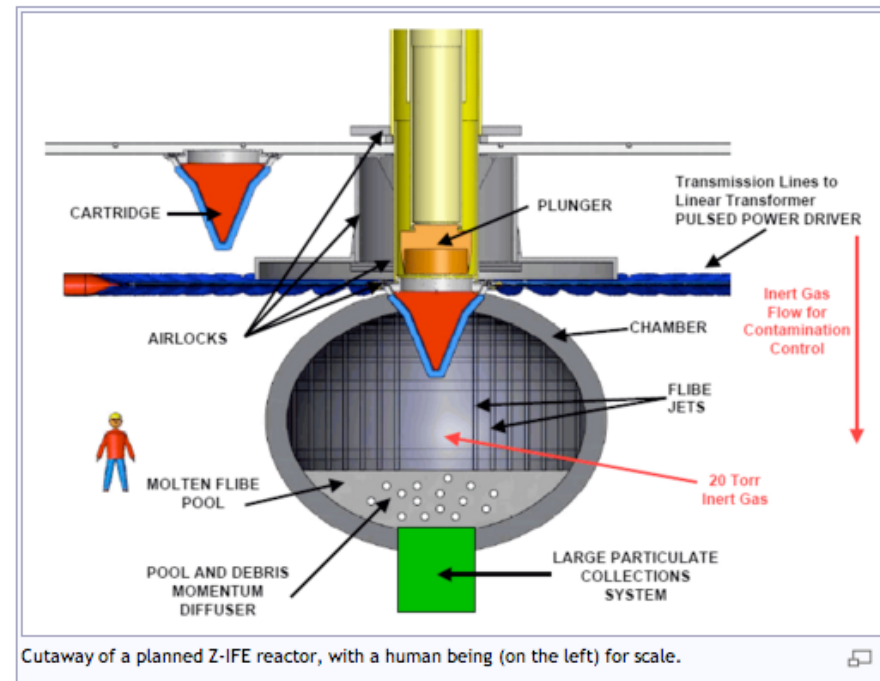
- Funded by OFES. It's research was directed towards HEDLP in 2003. HIFS-VNL (LBL, LLNL, PPPL)
- Last major IFE focused activity concluded with an integrated conceptual design, the Robust Point Design, published in 2003.
- An emphasis in HIF research has been the possibility of using thick liquid wall chambers. Such chambers may also support other IFE approaches.



(3) We heard updates for a pinch-based IFE vision has been explored based on Z research



- NNSA funding in FY04-05 and internal funding in FY06 allowed Sandia NL to engage the broader IFE community to advance the concept in an integrated way.



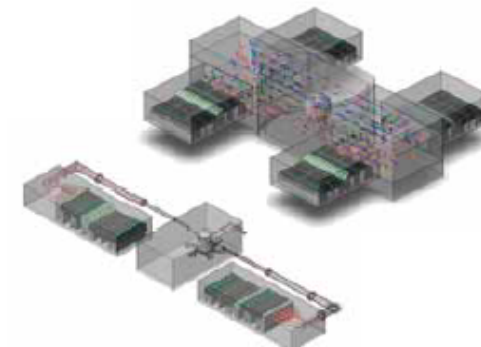
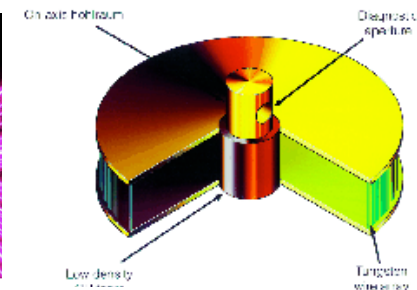
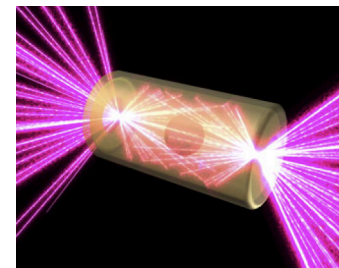
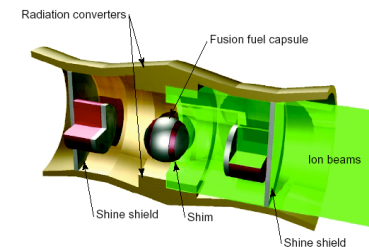
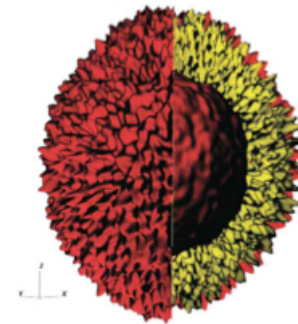
- Chamber is based on thick-liquid wall concept and the R&D is synergistic with the HIF approach.



HEDLP physics will be a major factor in making choices between these visions and in optimizing them. A sampling of issues...



- **Direct drive vs indirect laser drive:** Rayleigh-Taylor instability OK in both? Polar direct drive reduce symmetry requirements? One have favorable LPI compared to another?
- **Heavy ions:** can they be focused sufficiently to heat a target to fusion conditions? Beam ion/fuel interactions make direct drive attractive? Can beam “wobbling” stabilize the R-T instability?
- **Laser plasma interactions:** What wavelength will we need to make LPI acceptable for IFE? Should we consider a Z pinch, which has no LPI issues? Or heavy ions?
- **Fast ignition, shock ignition, and advanced targets:** Will HEDLP physics provide basis for these tools & enable increased gain and simpler power plant architecture?





Available and emerging facilities can access this space, enabling validation & verification of HEDLP understanding

The HEDLP thrusts and related physics can be mapped to programs that are or can be carried out on these facilities

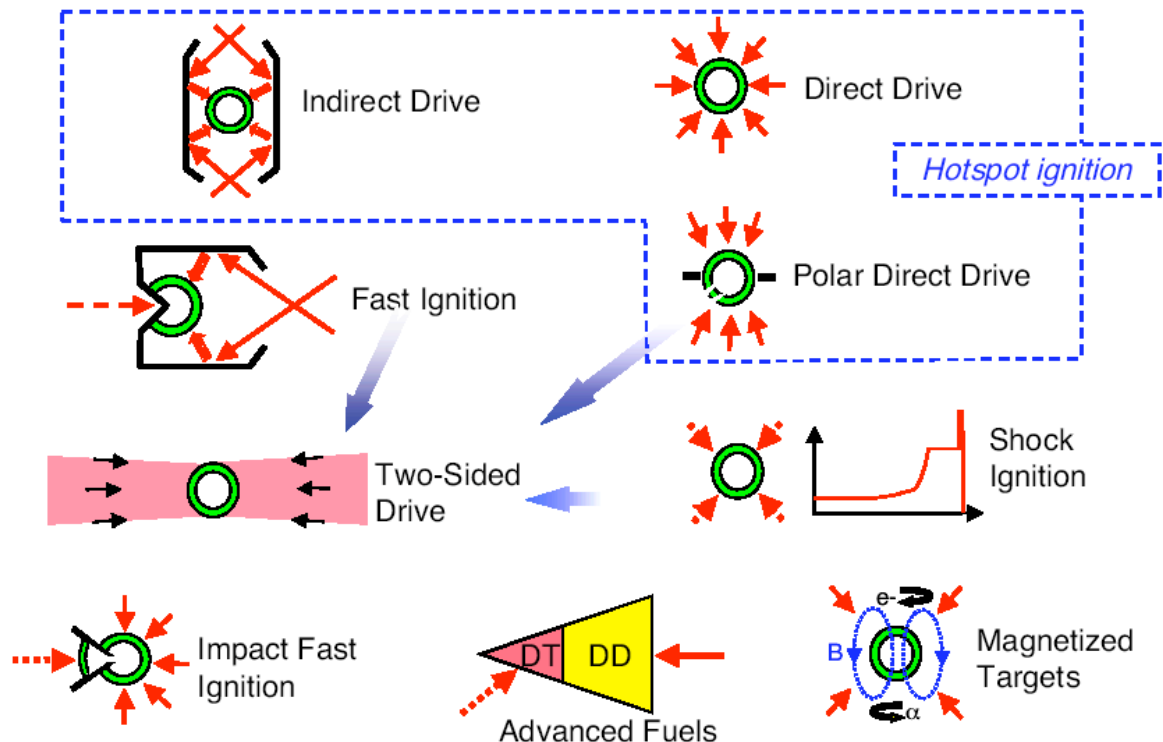


<i>HEDLP Thrust</i>	<i>IFE impact of HEDLP understanding</i>	<i>Facilities</i>
<i>Inertial confinement fusion</i> <ul style="list-style-type: none">• radiative hydrodynamics• compressible dynamics• laser-plasma interactions	<ul style="list-style-type: none">• Broad impact• Optimize target design & symmetry requirements• Identify laser λ requirements for a given target & driver approach• Help determine attractiveness of direct vs. indirect drive	<ul style="list-style-type: none">• NIF, ZR with ignition-scale capsule physics. Omega-EP, Nike, NDCX-II
<i>Fast ignition</i> <ul style="list-style-type: none">• Laser-material interactions and scaling• Electron transport & filamentation• Laser-plasma interactions and scaling	<ul style="list-style-type: none">• Broadly enabling.• Increased gain.• Potentially $\ll 4\pi$ illumination due to relaxed fuel assembly requirements; may enable liquid wall solutions for materials	Omega-EP, NIF, Titan and university petawatts. Z-beamlet on ZR
<i>Heavy ion driven HEDLP</i> <ul style="list-style-type: none">• Warm dense matter. Physics of ion beam compression & focus• Fast ion interaction with fuel	<ul style="list-style-type: none">• No LPI. Potentially $\ll 4\pi$ illumination; may enable liquid wall solutions for materials.• Ion direct drive may yield efficient coupling	NDCX; NDCX-II (HIFS-VNL). Relevant target physics on NIF, ZR

NIF ignition will serve as a linchpin in developing energy-related HEDLP, especially when supported by research on a range of facilities



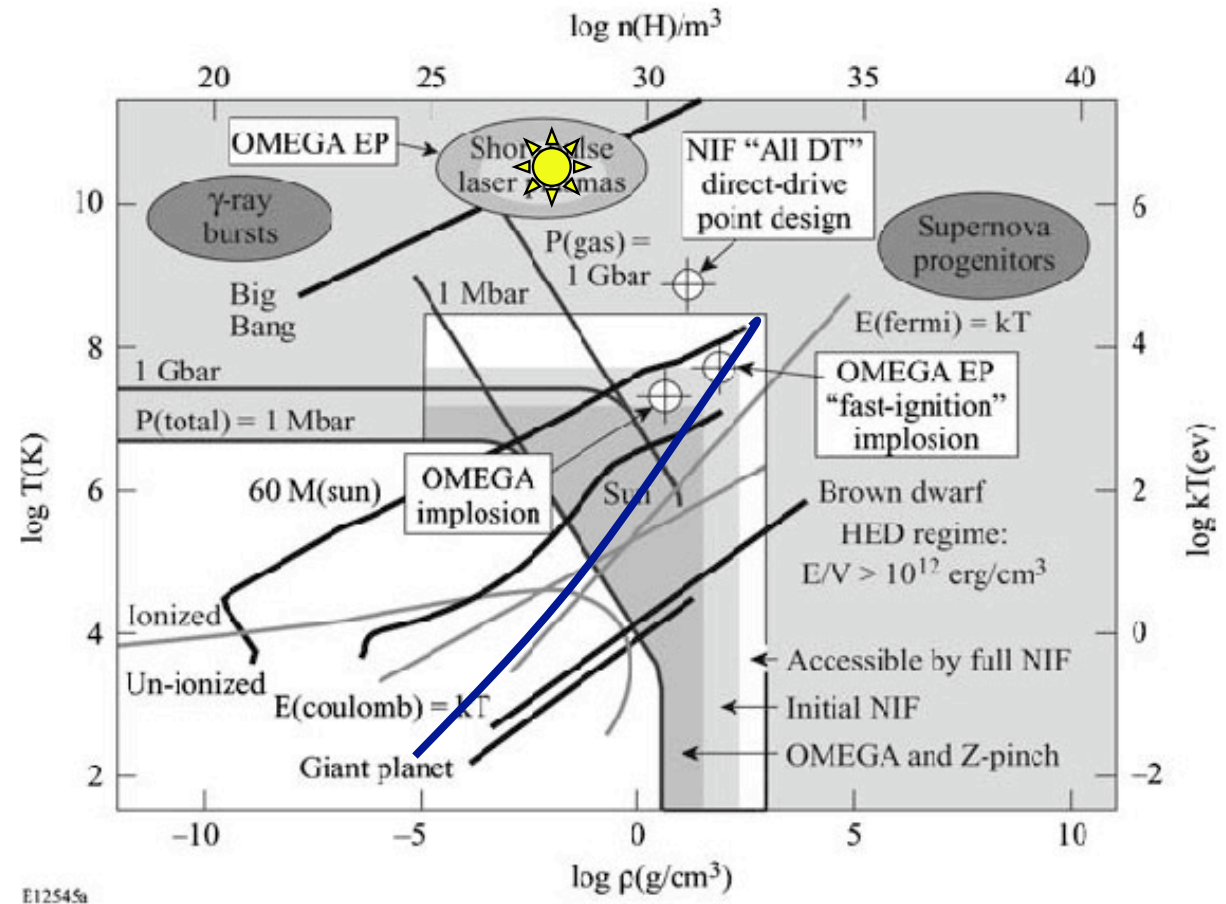
- Broad reach of HEDLP target physics: NIF will obtain first-of-a-kind required data on basic questions about HEDLP relevant to all mainline approaches.
- Post-ignition: optimizing the target through HEDLP will sharpen our vision for what an IFE plant can ultimately be.
- Approach: *benchmark the science in a range of conditions* on facilities to maximize the output of the science extracted from NIF and in extrapolating beyond NIF's results



Fast ignition presents a rich multi-scale physics challenge



- A huge physics challenge: filaments, self-fields, dynamic... Gradients that resemble discontinuities in the assembled, short-pulse - heated system
- Strong role for wide facility range: university-to-reactor-scale expt's (petawatts to Omega-EP to NIF) in validating HEDLP foundation for FI
- Increased NNSA facility use in FI will leverage investment in FSC and other FI work (OFES)



Gigagauss with gigamps!

*Potential IFE Impact: increased gain, simplified IFE plant architecture, potential use of thick liquid walls to short-circuit materials problems (as in HIF vision)*₁₃

Shock ignition is a prime example of front-line HEDLP science with a potentially high impact on IFE



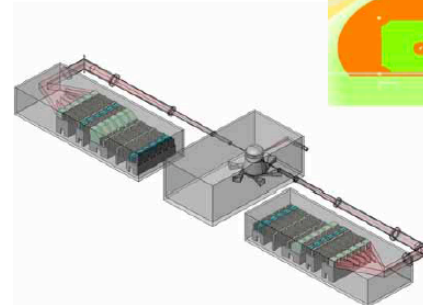
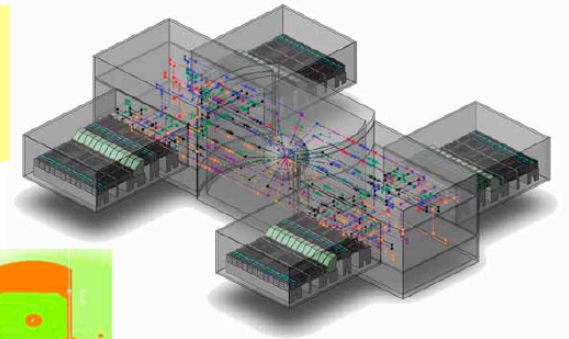
Can hydrodynamic shocks be used in ICF implosions to increase gain?

- Physics questions:
 - LPI driven by high intensity shocks
 - Robustness of ignition window to 2D-3D symmetry and stability

- Presently explored on Omega-EP and in simulation; looks promising for tests on NIF; value to an FTF discussed at the Workshop

Conventional Direct Drive

- 4Pi illumination
- Gain ~ 125 -150@2.5-3MJ
- Drywall chamber
- DPSSLs at 3 ω

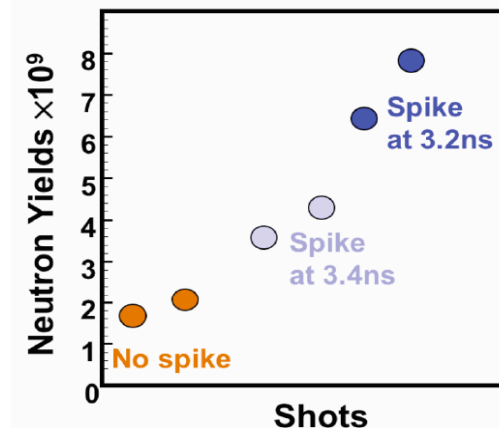
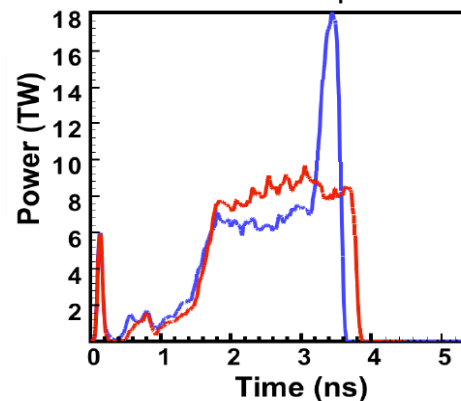


2-Sided Direct Drive + Shock/Fast Ignition

- 2-sided illumination
- Gain ~ 200 @1MJ
- Liquid wall chamber

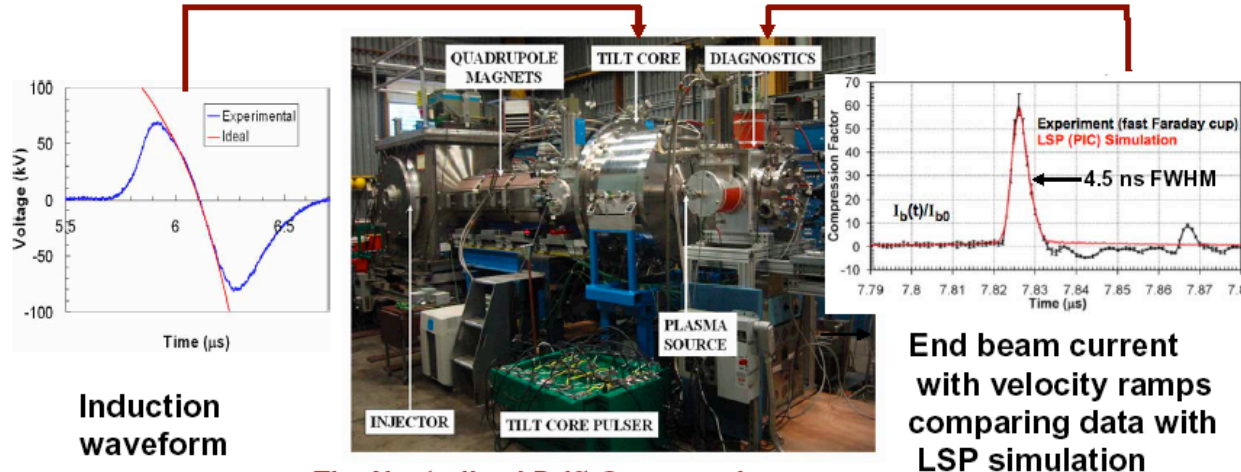
$$E_L = 17-18 \text{ kJ}$$
$$\alpha \approx 1.3$$

Pulse shape with and without shock spike



The neutron yield increases considerably when a shock is launched at the end of the pulse

Heavy ion fusion science yields tools for access to the warm dense matter regime



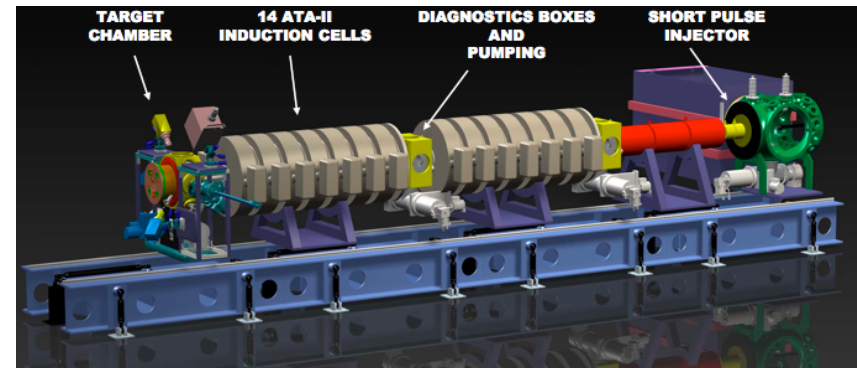
The Neutralized Drift Compression Experiment began operation in Dec 2004

- Compressed ion beams
==>> isochoric heating to WDM regime.
==>> EOS for planetary interiors, brown dwarfs...
- NDCX-I:
establishing beam compression & focus

- Proposed upgrade: NDCX-II
 - access to 1 eV WDM regime
 - Ion polar direct drive studies will be enabled with NDCX-II
 - *an OFES user facility for astronomy, condensed matter*

IFE impact

- HIF: build on high energy physics accelerator experience
- High efficiency of driver anticipated
- Focusing magnets avoid direct line of sight of debris
- Thick-liquid wall chambers
- Ion direct drive coupling studies would be enabled by NDCX-II

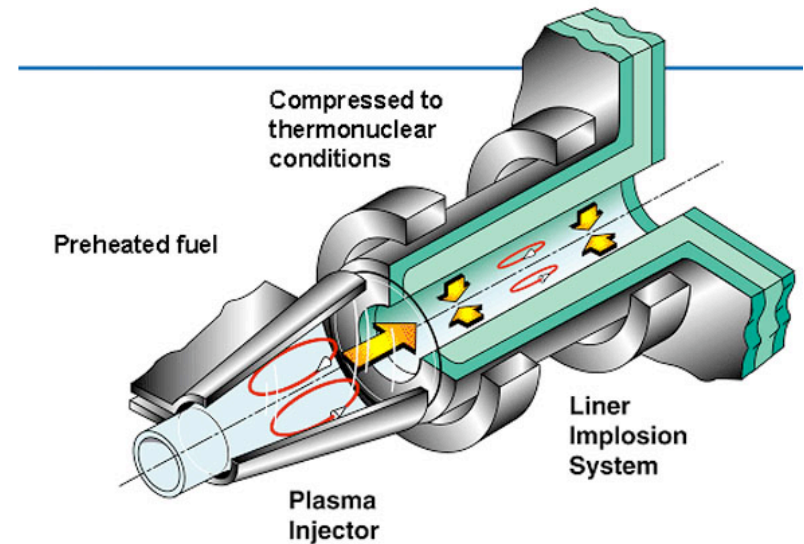


Tri-institutional OFES program, the HIFS-VNL: LBL, LLNL, PPPL

Emergent: magnetized inertial fusion experiments complement FI experiments with self-generated B fields

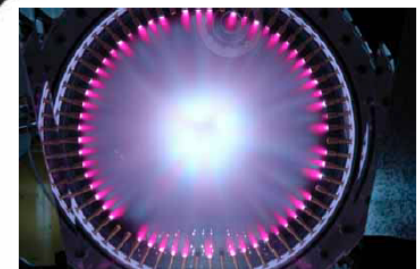
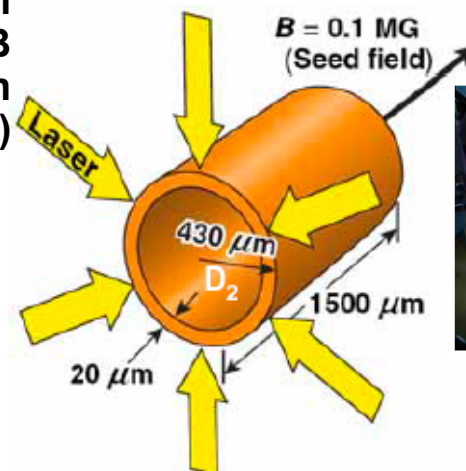


- > Mega-gauss B fields.
- Goal: Inertial particle confinement, magnetic energy confinement
- At LANL: goal to connect plasma injector with “Shiva Star” implosion liner system
- Potential IFE impact: Emergent concept, view as a hybrid between MFE and IFE. Explore reaping benefits of B field with compressed targets



Magnetized target liner implosions: LANL

Laser compression of seeded B field on Omega (FSC)



Plasma jets

NNSA/OFES facilities are essential to the validation and verification of many scientific issues central to IFE



- NIF ignition is going to change the mindset with respect to IFE and provide an opportunity to advance the science of the assembly, heating, and ignition of the fusion energy target, HEDLP.
- The impact of our understanding of HEDLP on the optimal vision for an IFE plant will be great. At the Workshop, one group's expressions of this: "A strengthened HEDLP effort will help enable the accurate assessment of the viability of drivers, target and chamber configurations, fuel cycles, and methods of power conversion"



Clean Energy: Humankind's Challenge